

EVALUATION & COMPARISON OF C.O.P OF SIMPLE VAPOUR COMPRESSION REFRIGERATION SYSTEM USING DIFFERENT REFRIGERANTS (R-134A, R-1234YF & R-1234ZE) IN THE CIRCUIT.

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ABSTRACT

World is highly concern about the exponential growth of global warming and energy demand, due to use of various refrigerants. Refrigerants used in VCRS are the most influencing agent in global warming & it is very important to select those refrigerants that have low impact on ozone layer and environment. This paper is a comprehensive review of experimental & theoretical studies of VCRS system using various refrigerants and their influence on atmosphere. From this paper we can also conclude the suitable alternative refrigerants for different VCRS.

KEYWORDS: VCRS, ODP, GWP, Alternative refrigerants & Blended refrigerants

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INTRODUCTION

The world is getting hotter day by day in the same manner the energy cost is also raising. To overcome from both the problems most of the researchers have started to find out the alternative source of energy to fulfil the need in economical context. So, main outcome from the investigations of various researchers are to work on-

- Energy conservation,
- Effect of refrigerants on environment.
- Reduction of energy in running cost.
- Reduction of substances that affect ODP & GWP.

The most common method for refrigeration & air conditioning is VCR (vapour compression refrigeration) system. Refrigerant R134a is used in the place of CFC's and HFC's because they have deplete ozone layer very fast. Refrigerant R134a is good but it also affects environment by high power consumption, high potential of global warming etc. To overcome from shortage of power consumption & energy efficient refrigeration system there is need of new and developed refrigerants are required which contains high heat transfer coefficient.

It has been observed that due to high level of GWP (global warming potential) it is now became mandatory to reduce the hydrofluorocarbon (HFC) emissions [1]. HFO refrigerants are the future refrigerants that are used in coming future. HFO refrigerants, or Hydrofluro-Olefins, are the latest class of refrigerants that have a much lower global warming potential than its HFC present alternatives. The entropy generation concept is useful to find out the

maximum exergy destruction value by taking different design parameters of exergy analysis. Number of researchers have performed exergy analysis of different energy conversion thermal systems for establishing different approaches to achieve exergy analysis and its adequacy for improving existing VCRS design by reducing exergy destruction in a most effective and simple manner [2-4] Padilla et al. [5] computed the exergy performance of a household vapor compression refrigeration system (VCRS) by using zeotropic mixture (R413A) by direct replacement of R12 and discover that the overall efficiency and performances of the existing system working on R-413A is much better than R-12. Arora and Kaushik [6] explained about exergy analysis in detail for actual VCRS cycle and constructed a computational model for calculation of COP (coefficient of performance), exergy destruction, exergetic efficiency and defects in efficiency for R-502, R-404A and R-507A and found that the R-507A is a better replacement of R-502 than R-404A. The efficiency error in condenser is probably high, and extremely low in liquid vapour heat exchanger for R-502, R-404A and R-507A refrigerants in the range of -50°C to 0°C evaporator temperature and in the range and 40°C to 55°C condenser temperature respectively.

It was observed that on the basis of literature researchers have investigated detailed 1st law analysis in terms of C.O.P (coefficient of performance) and 2nd law analysis in term of exergetic efficiency of simple vapour compression refrigeration system using HFO-1234yf and R1234ze refrigerants. Researchers still have not covered the irreversibility analysis or 2nd law analysis of modified vapour compression refrigeration systems using vapour liquid heat exchanger using new eco-friendly low GWP refrigerants.

VCRS Setup & Procedure

The experimental setup is installed in controlled environment of RAC (refrigeration and air conditioning) laboratory and compressor (Hermetically sealed) is used having 0.75 HP capacity. The induced air-cooled type of condenser unit is used for condenser motor and fan is fixed for circulation. The outer dia. of the condenser tube is $3/8''$ & the combination of $11'' \times 10'' \times 3$ tube in row is installed as per standard dimensions. To minimize the heat losses proper insulation is done over the evaporator unit, as well as between system & surrounding. The standard specification of copper pipes $0.36 \times 5 \times 1$ inches are used for circulation of refrigerant in the working components of the VCR system. The Capillary tube with different diameters are used in the system for cooling purpose. Refrigerants R-134a, R-1234yf and R-1234ze are used as the working fluid i.e refrigerant.



Figure 1: Photograph of Single Stage VCR Cycle

Just after the condenser a drier or filter, specially for R134a, R1234yf and R1234ze is installed in order to overcome from the problem of choking or clogging under the refrigerant pipes due to moisture. The main function of drier or filter is to restrict and absorb the complete moisture present in working fluid, that will form into ice in the flow line. To determine the pressure (high/low) of refrigerant in the system two pressure gauges (analogue) are also installed ranges from 0 to 300 PSI. Pressure gauge (bourdon tube) is placed to determine the discharge point pressure intensity at the exit of compressor.

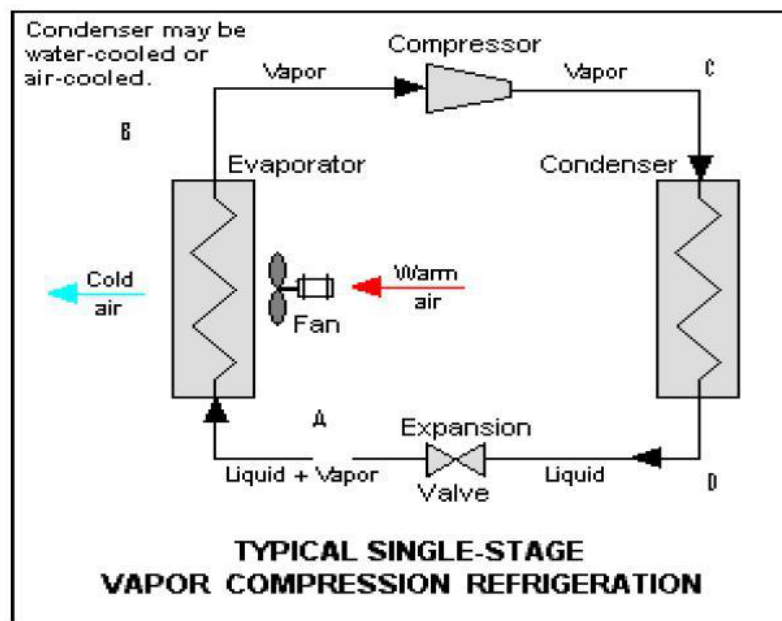


Figure 2: Schematic Diagram of Single Stage VCR Cycle

Both negative pressure (Vacuum) and positive pressure can be determined by Bourdon tube type pressure gauge in the vapour compression refrigeration system (VCRS). Suction point pressure of the compressor is calculated by bourdon tube type pressure gauge. High pressure gauge is installed between just before the capillary tube and the drier or filter unit. Similarly to find out the pressure of the fluid at low pressure return circuit a pressure gauge connected. Resistance temperature detectors (RTD, PT-100) are used to measure the temperatures at different points of vapour compression refrigeration system, this RTD works on the principal of change in temperature of coil will result in change in electrical resistance. For the investigation of the system and to determine the temperature a digital thermometer is also installed. The P-H chart gives the respective value of enthalpy, entropy and quantities with the readings of temperature & pressure, with the help of the input units the parameters like refrigerating effect, compressor work, heat addition & heat rejected were determined. The Ideal or Carnot C.O.P of single loop vapour compression refrigeration system is calculated by setting the temperature scale of the VCRS. The actual C.O.P is determined by taking the ratio between RE (refrigeration effect) to the work (Wc) done by compressor from the input values of the PH chart in the range of -200C to 400C respectively. Refrigerants R134a, R-1234yf and R-1234ze are used alternatively for the analysis in single stage VCR system.

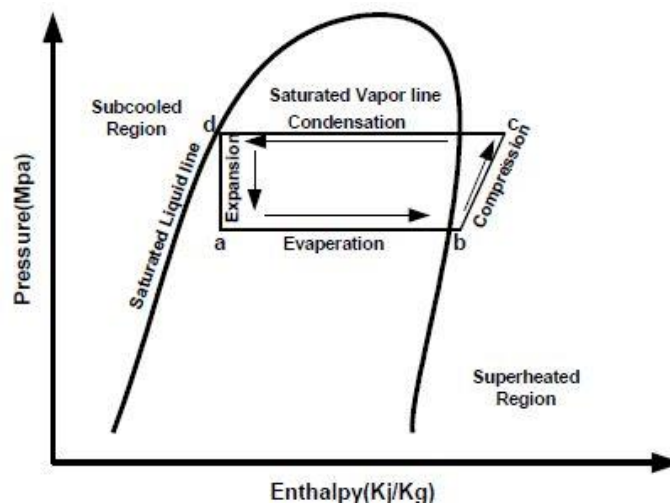


Figure 3: P-H Diagram

CALCULATION & OBSERVATION

Practical performed on single stage VCR & gives following results-

Temperature ($^{\circ}\text{C}$)	Table for R-134a				
	Pressure (Bar)	h_f (kJ/Kg)	h_g (kJ/Kg)	S_f (KJ/kg-K)	S_g (KJ/kg-K)
-20	1.3268	173.82	385.66	0.9009	1.7417
40	10.165	256.35	419.58	1.1903	1.7115

Temperature ($^{\circ}\text{C}$)	Table for R-1234yf				
	Pressure (Bar)	h_f (kJ/Kg)	h_g (kJ/Kg)	S_f (KJ/kg-K)	S_g (KJ/kg-K)
-20	0.49596	174.87	350.05	0.905	1.597
40	9.1707	254.9	387.17	1.1851	1.6075

Temperature ($^{\circ}\text{C}$)	Table for R-1234ze				
	Pressure (Bar)	h_f (kJ/Kg)	h_g (kJ/Kg)	S_f (KJ/kg-K)	S_g (KJ/kg-K)
-20	0.97	173.99	370.20	0.901	1.677
40	7.67	255.00	409.80	1.186	1.680

For R134a refrigerant (from the table)

The compression is isentropic at 40°C , So

$$S_1 = S_2 = S_g = 1.7115$$

$$\text{Or, } 1.7115 = X_1(1.7417) + (1 - X_1) 0.9009$$

$$X_1 = 1.7115 - 0.9009 / 1.7417 - 0.9009$$

$$X_1 = 0.9640 \text{ (Dryness fraction)}$$

To find out H_1 at -20°C

$$H_1 = X_1 h_g + (1 - X_1) h_f$$

$$H_1 = 0.9640 \times 386.66 + (1 - 0.9640) \times 173.82$$

$$H_1 = 378.99 \text{ kJ/Kg}$$

Similarly from the P-H chart at point “d” is the saturated liquid state at 40°C (Fig.3)

Hence,

$$S_3 = S_4 = 1.1903$$

Process d-a is reversible adiabatic, hence $S_3 = S_1$

Where, X_4 = the quality of refrigerant at point “a” ,

at -20°C

$$S_4 = X_4 S_g + (1 - X_4) S_f$$

$$X_4 = (1.1903 - 0.9009) / (1.7417 - 0.9009)$$

$$X_4 = 0.344$$

& similarly enthalpy at -20°C

$$H_4 = X_4 h_g + (1 - X_4) h_f$$

$$H_4 = 133.0 + 113.85 \times 0.344 = 246.85 \text{ KJ/Kg}$$

$$\text{Refrigeration effect} = H_1 - H_4 = 378.99 - 246 = 132 \text{ KJ/Kg}$$

It can be also written as,

$$H_1 - H_4 = T_e (S_1 - S_4)$$

$$H_1 - H_4 = (273.15 - 20)(1.7115 - 1.1903)$$

$$H_1 - H_4 = 131.94 \text{ KJ/Kg}$$

Due to inconsistency in the table properties the results are differ-

1 Tonn of refrigeration capacity, Q_e is 3.5166 Kw

Therefore, Mass flow rate

$$m \cdot (h_1 - h_4) = 3.51667 \text{ Kw}$$

$$m = 3.51667 / (378.99 - 246.85) = 0.0266 \text{ kg/s}$$

$$\text{Compressor's work done } |W_c| = m \cdot (h_2 - h_1) = 1.07 \text{ KW}$$

$$\text{Turbine's work done } |W_t| = m \cdot (h_3 - h_4) = 0.2527 \text{ KW}$$

$$\text{Net Work } |W_{net}| = |W_c| - |W_t| = 0.8173 \text{ KW}$$

Heat exhausted by condenser unit

$$Q_c = m \cdot (h_2 - h_3) = m \cdot T_c (S_2 - S_3) = 4.34 \text{ KW}$$

Therefore, Coefficient of performance (COP) will be,

$$\text{COP} = Q_c / W_{\text{net}} = 3.51167 / 0.8173 = 4.29$$

Similarly, For R1234yf refrigerant (from the table) with same procedure

$$X_2 = 1.6075 - 0.905 / 1.597 - 0.905 = 1.061$$

$$h_1 = 360.7 \text{ KJ/Kg}$$

$$X_4 = 0.404$$

$$h_4 = 245.64 \text{ KJ/Kg}$$

$$\text{Therefore, Refrigerating effect} = h_1 - h_4 = 115.06 \text{ KJ/Kg}$$

Similarly,

$$h_1 - h_4 = T_e (S_1 - S_4) = 106.9 \text{ KJ/Kg}$$

Therefore, m. (mass flow rate)

$$m \cdot (h_1 - h_4) = 3.51667 \text{ Kw}$$

$$m = 3.51667 / 106.9$$

$$m = 0.0328 \text{ kg/s}$$

$$\text{Compressor's work done } |W_c| = m \cdot (h_2 - h_1) = 0.8682 \text{ KW}$$

$$\text{Turbine's work done } |W_t| = m \cdot (h_3 - h_4) = 0.303 \text{ KW}$$

$$\text{Net Work } |W_{\text{net}}| = |W_c| - |W_t| = 0.564 \text{ KW}$$

Heat exhausted by Condenser unit

$$Q_c = m \cdot (h_2 - h_3) = m \cdot T_c (S_2 - S_3) = 4.33 \text{ KW}$$

Therefore, Coefficient of performance (COP) will be,

$$\text{COP} = Q_c / W_{\text{net}} = 3.51167 / 0.8173 = 4.22$$

Similarly, For R1234ze refrigerant (from the table) with same procedure again

$$X_2 = 1.6075 - 0.905 / 1.597 - 0.905 = 1.003$$

$$h_1 = 370.2 \text{ KJ/Kg}$$

$$X_4 = 0.367$$

$$h_4 = 245.9 \text{ KJ/Kg}$$

$$\text{Therefore, Refrigerating effect} = h_1 - h_4 = 124 \text{ KJ/Kg}$$

Also,

$$h_1 - h_4 = T_e(S_1 - S_4) = 125 \text{ KJ/Kg}$$

Therefore, Mass flow rate

$$m \cdot (h_1 - h_4) = 3.51667 \text{ Kw}$$

$$m = 3.51667 / 125$$

$$m = 0.02813 \text{ kg/s}$$

$$\text{Compressor's work done } |W_c| = m \cdot (h_2 - h_1) = 1.1139 \text{ KW}$$

$$\text{Turbine's work done } |W_t| = m \cdot (h_3 - h_4) = 0.256 \text{ KW}$$

$$\text{Net Work } |W_{\text{net}}| = |W_c| - |W_t| = 0.8579 \text{ KW}$$

Heat exhausted by Condenser

$$Q_c = m \cdot (h_2 - h_3) = m \cdot T_c (S_2 - S_3) = 4.35 \text{ KW}$$

Therefore, Coefficient of performance (COP) will be,

$$\text{COP} = Q_c / W_{\text{net}} = 3.51167 / 0.8173 = 4.21$$

OBSERVATION & CONCLUSIONS

Following conclusions were drawn from present investigations-

- Thermodynamic performance using R-1234ze results in better first and second law performances than R1234yf and R134a.
- The performance of HFO refrigerants is slightly less than HF1234ze (E), however it has similar refrigerating properties and can easily replace HFC-R134a in all VCR systems.
- The exergy destruction in compressor is highest for all HFO refrigerants.
- The exergy destruction in evaporator is second highest.
- In throttle valve the exergy destruction is lowest.
- Exergy destruction ratio is increasing as evaporator and condenser temperatures is increasing.
- Coefficient of performance of modified vapour compression system is increasing when evaporator temperature is increasing for all HFO refrigerants.

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